International Workshop on Ice-drilling Technology
Nagaoka University of Technology, Japan

ISSUES IN SUBSURFACE EXPLORATION OF ICE SHEETS

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Exploration of the deep subsurface ice sheets of Earth, Mars, Europa, and Titan has become a major consideration in addressing scientific objectives in climate change, extremophile biology, exobiology, chemical weathering, planetary evolution and ice dynamics. This sort of exploration on Earth has been accomplished through ice coring, for chemical and crystallographic analysis, and sounding radar, for structural analysis, and the results from these studies have been of high value, most recently in elucidating the temporal and circulation aspects of climate change on Earth. For some applications coring and remote sensing techniques are not optimal; these applications include situations in which the ice cores are too warm for successful core retrieval, investigations which require strict sterilization, and planetary environments for which in-situ observations are the extent of exploration technologically possible. For these situations we have modeled, designed, and are in fabrication phase of a vehicle for deep (several kilometer scale) mobility in ice, the Cryobot (analogous to the Philberth thermal probes of the late 1960's). The Cryobot moves vertically through ice by melting the ice below it and displacing the meltwater, which refreezes above the probe. The Cryobot carries and pays out its tether which is used to convey power and control signals down and data up to a surface station; in future the Cryobot will also deploy scientific instruments. Ice melt is accomplished both passively through resistive heating and actively through jetting of heated water forward, in the fashion of a miniature hot-water drill, a technology of long and extensive use in ice sheet research. We will discuss test results and design issues including the fluid dynamics of hot-water jetting, approaches to maintaining vertical attitude, tether management.

Issues in Subsurface Exploration of Ice Sheets

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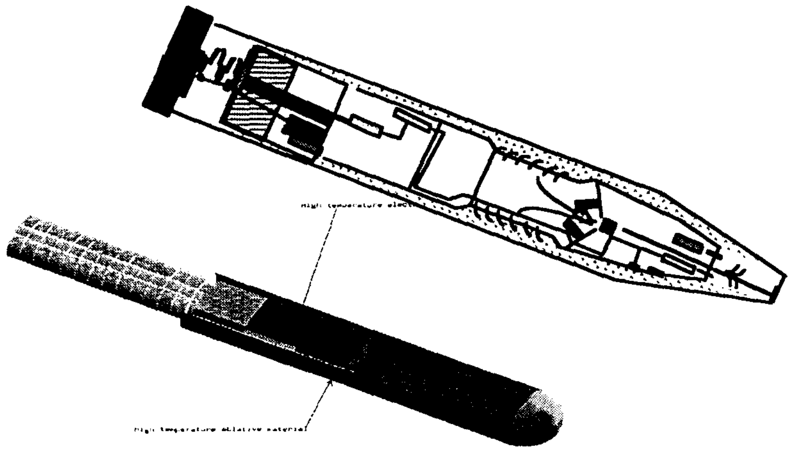
CETDP ACTIVE THERMAL PROBES FOR ICE SITES



Two Point Designs for Thermal Probes, vehicles for movement in ice

Description:
Thermal Ice Probe technology development for advanced in-situ capability and mobility.

Objectives:
FY '00: Establish basic technology of thermal probe
FY '01: Develop technologies for tethered applications (Mars / Earth)
FY '02: Develop technologies for accommodating particles in ice, cold ice, ice sampling

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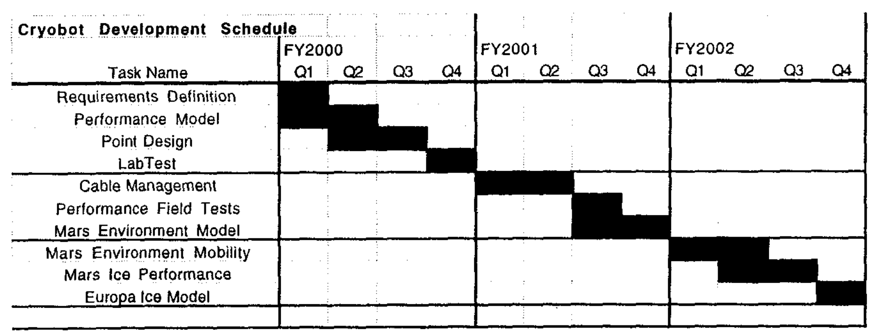
FY00 Level 1 Goals:
Develop a cryobot mobility performance model through ice. Design and build prototype system for laboratory tests. Show ability to travel 5 meters in clear water ice.



Active Thermal Probe

Technical Accomplishment:
Melting performance modeling using water jetting as a vortex drill.

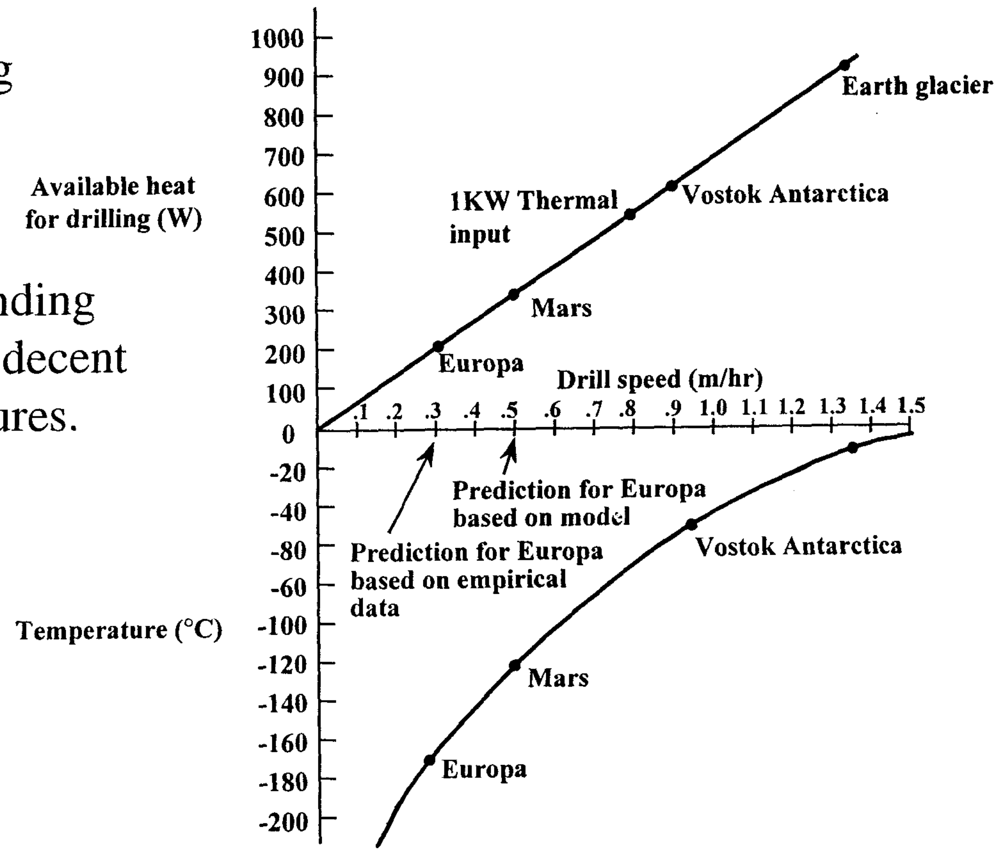
Knowledge gathered helps understanding relationships between power inputs, decent rates, and ice environment temperatures.

Significance to NASA:

•Mobility through subsurface ice environments is possible.

•New access for instrumentation tools for scientific community.

•Subsurface exploration of icy planetary environments is feasible.



Drill Speed vs Heat and Temperature

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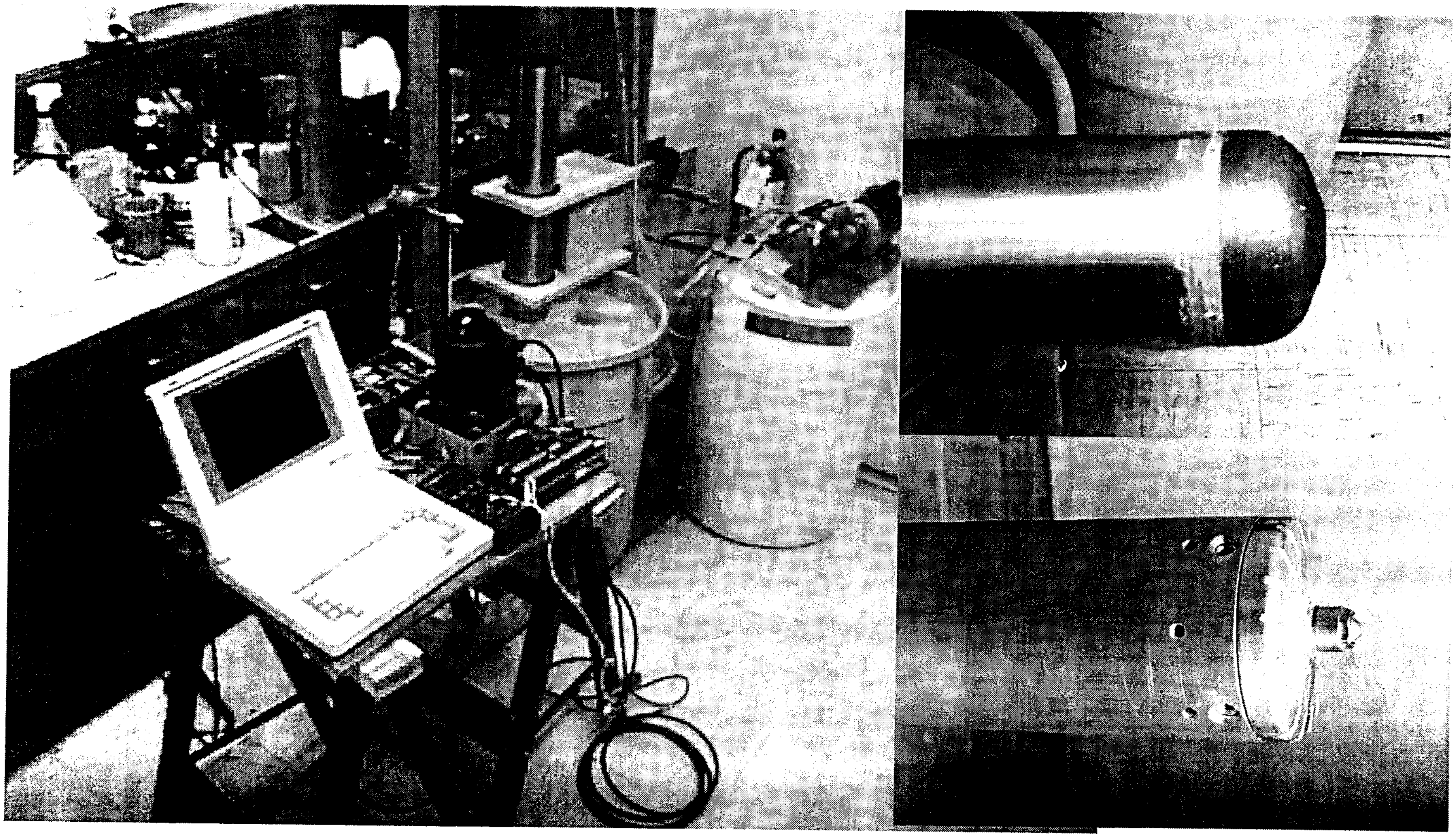
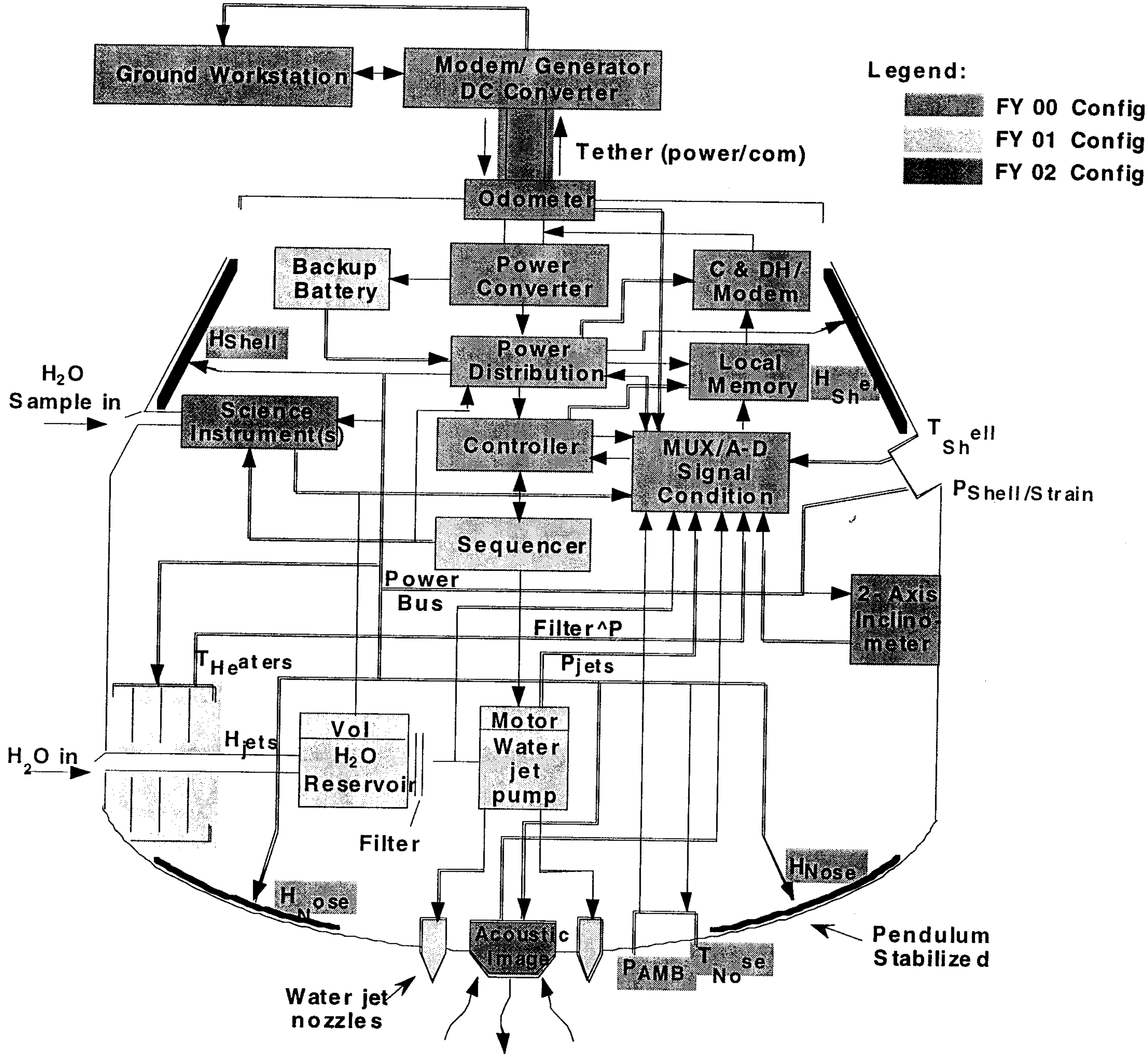
Verification Modeling Tests



CRYOBOT DRILLING PARAMETERS PHASE 1

• MELTING POWER	0.6 - 0.8 kW
• DRILLING NOZZLE DIA	1.0 - 1.25 mm
• WATER TEMPERATURE AT NOZZLE	20 - 25°C
• WATER TEMPERATURE	5 - 6°C
• RETURN WATER PRESSURE	1 - 2 bar
• WATER JET VELOCITY	10 - 20 m/s
• WATER FLOW RATE	1 - 1.5 l/min
• DRILLING SPEED	0.3 - 1.0 m/h
• DRILLING EFFICIENCY	80 - 90 %
• ICE TEMPERATURE	-10°C
• CRYOBOT OUTER DIA.	10 - 12 cm
• CRYOBOT LENGTH	1 - 2 m

Cryobot Functional Control Block Diagram



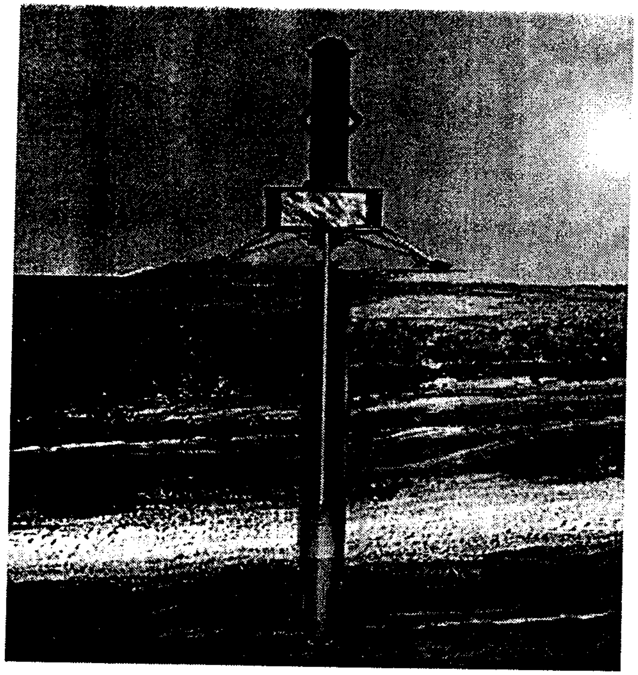
Plans for FY 01 and Beyond

- **FY2001**
- Objectives
  - Model/Test sediment affects
  - Study Cryobot for Mars application/performance
  - Fully integrate system
    - Package electronics and Pump systems
    - Tether bay development
    - Suspension system
- Testing Situations
  - Perform short decent field test
  - Plan deep decent field test

Plans for FY 01 and Beyond

- **FY2002**
- Objectives
  - Model/Test
    - Steering/Obstacle Avoidance
    - Slow Melt
  - Study Cryobot for Europa application/performance
  - Sonar imaging integration
- Testing Situations
  - Deep decent w/ Sediment/debris
- TRL 5-7

Mars Polar Stratigraphy Mission



Critical Technology

- •Subsurface mechanical or thermal probe.
- •Precision navigation and landing (laser radar)
- •In situ instrumentation for cryospheric science

Other Important Technology

- • Subsurface navigation and communications
- • Power sources

- *Science Objectives*
  - Determine the stratigraphy of the layered sedimentary deposits of the north polar cap
  - Determine the age and depositional/erosional state of the deposits
  - Inventory the distribution and total amount of water in the north polar cap
  - Search for fossil evidence of life
- *Mission Description*
  - Landing site: Within region of permanent water ice
  - Subsurface : Descend 50 to 200m into the deposits
  - Telecon/Navigation: Uses Microsat network
  - Cost: TBD
  - Option: Return samples to surface for analysis
- *Measurement Strategy*
  - Determine composition and density as the probe descends through the ice deposits
  - Image subsurface features within the ice
  - Perform wet chemistry measurements once the surface is sealed.